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STUDY OF RESIDUAL STRESSES AND DISTORTION IN STRUCTURAL WELDMEN--ETC(U)
OCT 78 K MASUBUCHI, A PAPAZOGLOU N00014-75-C-0469

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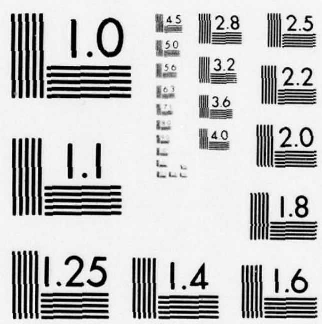

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF OCEAN ENGINEERING
CAMBRIDGE, MASS. 02139

FIRST PROGRESS REPORT, no. 1,

of

Contract N00014-75-C-0469
(MIT OSP #82558)

STUDY OF RESIDUAL STRESSES AND DISTORTION IN STRUCTURAL WELDMENTS IN HIGH-STRENGTH STEELS.

to

Office of Naval Research

44p

10 October 1978

by

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1. INTRODUCTION AND SUMMARY

The objective of this research program, which started on December 1, 1977, is to study analytically and experimentally residual stresses and distortion in structural weldments in high-strength steel.

The program includes (1) generation of experimental data and (2) development of analytical systems. HY-130 is the primary material to be investigated; a limited number of experiments are, however, to be done with low-carbon steel. Experiments are to be made using two welding processes, multipass gas metal arc welding processes and electron-beam welding (one pass).

More specifically,

Materials: HY-130 steel (with some control specimens in low-carbon steel)

Thickness: 1 inch (with some specimens 1/2" thick)

Welding processes: Electron beam (EB) and multipass gas metal arc (GMA) processes.

Specimen geometries: The following types of specimens are considered

a. Butt welds in thick plates
   (1) Unrestrained butt welds
   (2) Simple restrained butt welds
   (3) Restrained welds simulating practical weldments

b. Girth welds of cylindrical shells
   (4) Girth welding along the groove of a cylindrical shell
   (5) Girth welding between unstiffened cylindrical shells

The work to be performed has been divided into two main tasks:

Task 1: Research on butt welds in thick plates

Task 2: Research on girth welds in cylindrical shells

The entire program is expected to be completed in three years. Table 1 illustrates tasks and phases included in this study. Tables 2-a and 2-b show planned progress of Tasks 1 and 2, respectively, as appearing in the original proposal dated July 1977.

Table 3 summarizes test conditions and the number of specimens to be prepared. Since the major effort of the proposed research is to develop analytical systems, experiments will be made on few specimens to verify

the analysis. Table 4 illustrates how analyses will be improved during the three-year program.

For the most part, the program has been carried out as it was originally proposed. The few changes made will be dealt with in the appropriate places.

TABLE 1 Tasks and Phases of the Program

	Task 1: Thick Plate	Task 2: Cylindrical Shell
First Year	1.1 Develop details of research plan	2.1 Develop details of research plan
	1.2 Experiments on unrestrained butt welds	2.2 Experiment on girth welding along groove of a cylindrical shell
	1.3 Analysis of data obtained in 1.2	2.3 Analysis of data obtained in 2.2
Second Year	1.4 Develop details of research plan	2.4 Develop details of research plan
	1.5 Measurement of residual stresses in specimens made in 1.2	2.5 Measurement of residual stresses in specimens made in 2.2
	1.6 Experiment on simple restrained butt welds	2.6 Experiment on butt welds between unstiffened cylindrical shells
	1.7 Analyses of data obtained in 1.5 and 1.6	2.7 Analyses of data obtained in 2.5 and 2.6
Third Year	1.8 Develop details of research plan	2.8 Develop details of research plan
	1.9 Experiment on restrained cracking test specimens	2.9 - - -
	1.10 Measurement of strain energy release on specimens made in 1.6 and 1.9	2.10 Measurement of residual stresses in specimens made in 2.6
	1.11 Analysis of data obtained in 1.9 and 1.10	2.11 Analysis of data obtained in 2.10
	Preparation of the Final Report	

↓ Information on residual stresses and strain energy release in specimens used for weld cracking and stress-corrosion cracking

↓ Information on residual stresses and distortion of welded cylindrical shells

TABLE 2-a Planned Progress of Task 1

	First Year	Second Year	Third Year.
1.1 Develop details of research plan	↔		
1.2 Experiments on unrestrained butt welds	↔		
1.3 Analysis of data obtained in 1.2	↔		
1.4 Develop details of research plan		↔	
1.5 Measurement of residual stresses in specimens made in 1.2		↔	
1.6 Experiments on simple restrained butt welds		↔	
1.7 Analysis of data obtained in 1.5 and 1.6		↔	
1.8 Develop details of research plan			↔
1.9 Experiment on restrained cracking test specimens			↔
1.10 Measurement of strain energy release on specimens made in 1.6 and 1.9			↔
1.11 Analysis of data obtained in 1.9 and 1.10			↔
Reports			
Annual reports	↔	↔	↔
Final report			

Table 2-b Planned Progress of Task 2

	First Year	Second Year	Third Year
2.1 Develop details of research plan			
2.2 Experiment on girth welding along a groove of a cylindrical shell			
2.3 Analysis of data obtained in 2.2			
2.4 Develop details of research plan			
2.5 Measurement of residual stresses in specimens made in 2.2			
2.6 Experiments on butt welding between unstiffened cylindrical shells			
2.7 Analysis of data obtained in 2.5 and 2.6			
2.8 Develop details of research plan			
2.9 - - -			
2.10 Measurement of residual stresses in specimens made in 2.7			
2.11 Analysis of data obtained in 2.10			
Reports			
Annual reports			
Final report			

TABLE 3 Experimental Conditions and Number of Specimens

Specimen Geom.			Thick Plate		Cylindrical Shell	Total
Thickness			1" thick		1/2" thick	
Material			Low-carbon steel	HY-130	HY-130	
Year	Steps	Processes				
First Year	1.2	EB	$1 + \alpha^{(1)}$	$1 + \alpha^{(1)}$	-	$5(1 + \alpha)$
	2.2	GMA	$1 + \alpha$	$1 + \alpha$	$1 + \alpha^{(1)}$	
Second Year	1.5	EB	Specimens made in 1.2 & 2.2 will be used			
	2.5	GMA				
	1.6	EB	-	2	-	$5 + \alpha$
	2.6	GMA	-	2	$1 + \alpha$	
Third Year	1.9	EB		$1 + \alpha^{(2)}$		$2(1 + \alpha)$
		GMA		$1 + \alpha^{(2)}$		
	1.10 2.10	EB	Specimens made in 1.6 & 2.6 will be used			
		GMA				

NOTE: (1) $(1 + \alpha)$ means that two specimens will be prepared, of which one will be the primarily specimen. If the first test is conducted successfully, only a limited experiment will be made on the second specimen.

(2) 2-inch thick plate may be used.

TABLE 4 Planned Improvements of Analyses

Current Status	I.0. Manuals #3, #4, #5	II.0. Muraki's analysis
First Year	Unrestrained Butt Welds I.1. Modify to improve compatibility I.2. Include effects of metallurgical transformation I.3. Include analysis of multipass welding	Groove Weld II.1. Modify to improve compatibility II.2. Develop simple analyses
Second Year	I.4. Analysis of residual stress I.5. Include effects of restraint I.6. Develop analysis of strain energy release	II.3. Analysis of residual stress II.4. Include effects of metallurgical transformation II.5. Include analysis of multipass welding
Third Year	I.7. Develop analysis of practical restrained specimens	(II.6. Possible analysis of effect of stiffeners)
	I.8. Develop final versions of computer programs	II.7. Develop final versions of computer programs

NOTE: This table lists those activities related to improvement of analyses. Efforts which will be spent for analyzing existing data, and possible modification of programs are not included here.

2. PROGRESS OF TASK 1 - THICK PLATES

December 1, 1977 to August 31, 1978

2.1 General Status

According to the original proposal dated July, 1977, the research during the first year would include the following, under Task 1:

1.1 Development of details of research plan during the first year.

1.2 Experiments on unrestrained butt welds

1.3 Analysis of data obtained in 1.2

The research program has been carried out as originally proposed with some modifications in step 1.3 .

2.2 Development of Details of the Research Plan During the First Year (Step 1.1)

It was decided that experiments would be made to determine changes of temperatures and transient thermal strains during butt welding unrestraint joints. After consulting representatives of the O.N.R. and the Electric Boat Division of General Dynamics Corporation, the experimental details were finalized as follows:

Two plates 24 inches long, 12 inches wide, and 1 inch thick would be joined resulting in a 24 in. x 24 in. configuration (Fig. 1). A total of 8 specimens would be prepared as follows:

Low-carbon steel, gas metal arc welding (multipass) ... 2

HY-130 steel, gas metal arc welding (multipass)........ 2

Low-carbon steel, electron beam welding (one pass)..... 2

HY-130 steel, electron beam welding (one pass) 2

In each of the above four test conditions, one specimen would be used for the primary testing and the other specimen would be used as the back-up.

Measurements would be made of:

(1) Temperature changes using thermocouples

(2) Changes of thermal strains using electric resistance strain gages.

The weld joint configuration would be that of a double vee for the gas metal arc welding (Fig. 2) and that of a square butt for the electron beam welding tests.

Low-carbon steel specimens were included as the control. Tests on

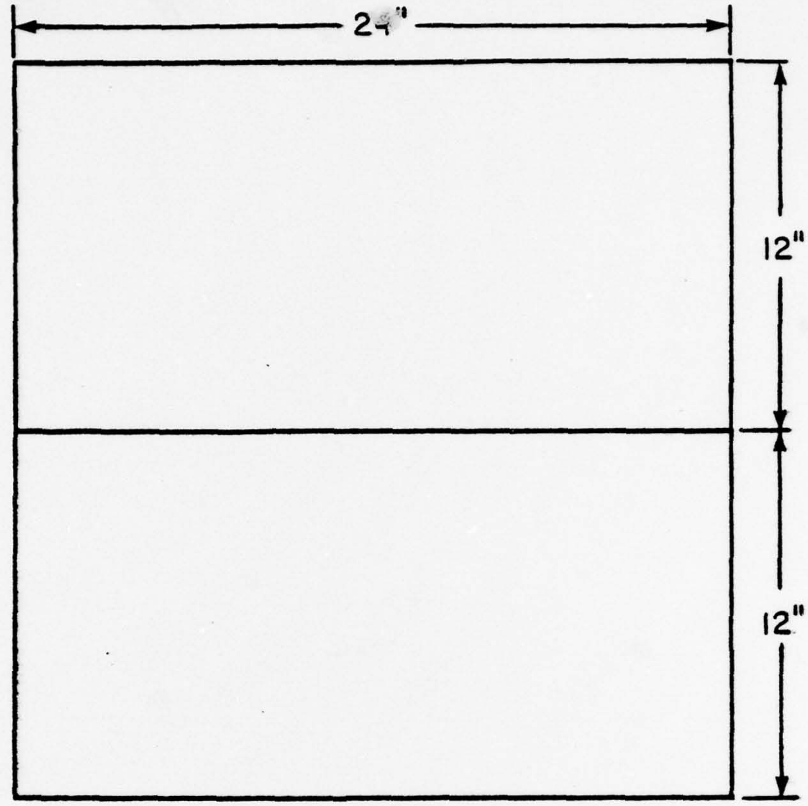

Figure 1 Test Plate Arrangement For Unrestrained Butt Joints

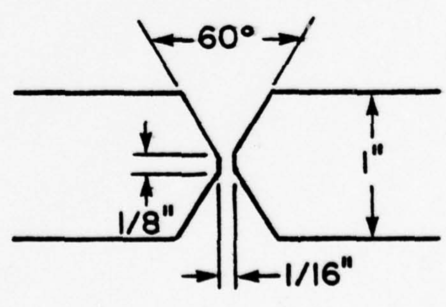

Figure 2 Weld Joint Configuration For the GMAW Experiments

electron-beam welding were included to generate information on temperature and strain changes during modern, high heat-intensity processes such as EB and laser welding. Tests of multipass welding using the GMA process were included to represent current shipyard practices.

Since M.I.T. has no facility with the ability to weld plates of the size mentioned above using EB welding, it was decided that these tests would be carried out at the facilities of the Applied Energy Co., Stoneham, Mass.

Regarding Step 1.3, it was decided to compare the experimental results obtained in Step 1.2 with predictions made using the M.I.T. one-dimensional computer program for the analysis of thermal stresses and metal movement during welding (described in Section IV, Manual #2 of the monograph "Analysis of Welded Structures: Design and Fabrication Considerations" developed by Masubuchi under an O.N.R. contract)*. This decision was made in order to evaluate the program for the case of multipass and one-pass EB welding of a thick plate, although it was well understood that the one-dimensional assumptions were not valid in the case of the tests.

Finally, it was decided that no comparison should be made with predictions using the existing two-dimensional finite-element program before the proposed modifications (see Table 4) were completed. One of the primary reasons for such a decision was the high cost in excess of $300. of a single run using this program.

2.3 Experiments on Unrestrained Butt Welds (Step 1.2)

The following two theses, dealing with Step 1.2 and part of Step 1.3, have already been completed:

1. Lipsey, M. D., "Investigation of Welding Thermal Strains in High Strength Quenched and Tempered Steel", Ocean Engineer Thesis, M.I.T., June 1978.

2. Coneybear, G. W., "Analysis of Thermal Stresses and Metal Movement During Welding", S.M. Thesis, M.I.T., May 1978.

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*Contract N00014-75-C-0469 NR 031-773 (M.I.T. OSP #82558) "Development of Analytical and Empirical Systems for Parametric Studies of Design and Fabrication of Welded Structures", December 1974 - November 1977.

A summary of the results appearing in these two theses are presented below.

2.3.1 GMA Welding Tests

The experimental investigation of the gas metal arc welding specimens was undertaken by Lipsey. Three specimens were used: one was a low-carbon steel with a designation 1020 and the other two were HY-130 steels. Welding on all tests was performed by the semi-automatic GMA method. Table 5 summarizes the welding conditions used. Note that six passes were required to fill the upper half of the double-V groove. Pre-heat was applied by oxy-acetylene torches and monitored by the installed thermocouples. Interpass temperature was also monitored by the installed thermocouples.

Three kinds of measurement were taken during the welding and cooling stages of the experiments:

(1) Transient thermal strains were measured using adhesive bonded, electric resistance strain gages.

(2) Temperature changes were measured on the surfaces of the specimen plates using adhesive bonded, Chromel/Alumel thermocouples.

(3) Metal movement, as measured by transverse shrinkage, was measured during one of the experiments.

Figures 3 and 4 show the thermocouple and strain gage locations on the specimens. Finally, it should be noted that the plates to be welded were positioned on knife edge supports, so that the unrestrained simply supported boundary condition could be approximated as close as possible.

Lipsey's thesis contains many figures showing results obtained during the experiments. Figures 5, 6, and 7 show typical results of transient thermal strains (in units of microstrain, which equals 10^{-6} in/in) during pass 4 for the two HY-130 and the 1020 specimens respectively. Each curve represents the longitudinal thermal strain history as measured by the strain gage located at the position shown. The time axis refers to the time elapsed from the start of one pass until the start of the next pass. The time scales for each pass have been adjusted and the data is presented so that the arc passes the point of observation at t = 40 sec. This point is marked on each graph. Note also the change in scale at 100 sec to that of a log plot from 100 to 1000 seconds. All three figures (5 through 7) show, qualitatively, similar results, something which was expected. Note that all curves do not

TABLE 5 Welding Conditions For The GMA Welded Specimens

TEST PLATE	1020	HY-130 SPECIMEN I	HY-130 SPECIMEN II
WELD TYPE	BUTT	BUTT	BUTT
PROCESS	GMA	GMA	GMA
ARC VOLTS	26	25	25
POLARITY	DCRP	DCRP	DCRP
TRAVEL SPEED (tpm)	12	12	12
HEAT INPUT (Kjoules/in)	39	37	37
FILLER WIRE	.0625" A-675	0.045" Linde-140	0.045" Linde-140
SHIELDING GAS	AR, 25% CO_2	AR, 2% O_2	AR, 2% O_2
NUMBER OF PASSES	6	6	6
PREHEAT & INTERPASS TEMP.	150-175°F	150-175°F	150-175°F

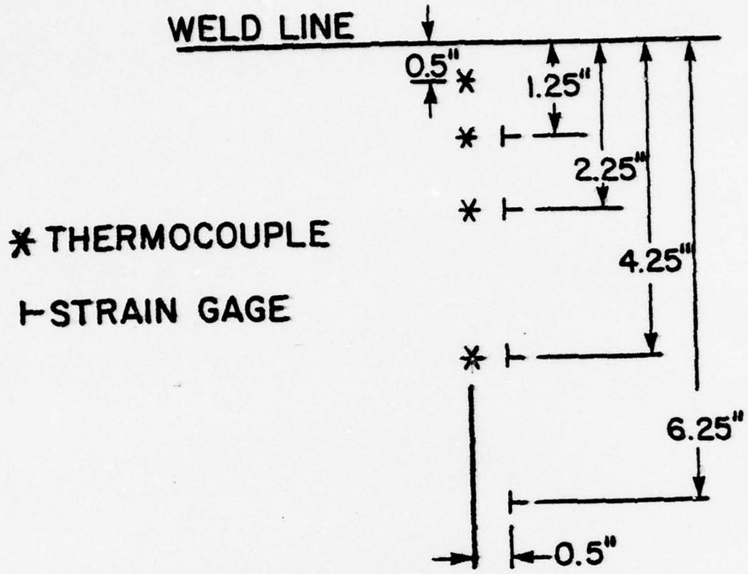


FIGURE 3 Thermocouple And Strain Gage Location on HY-130 Specimen I And 1020 Steel (GMAW)

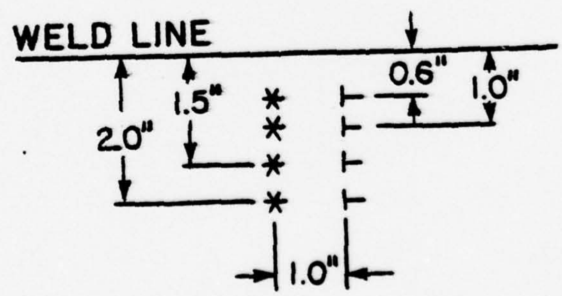


FIGURE 4 Thermocouple And Strain Gage Location on HY-130 Specimen II (GMAW)

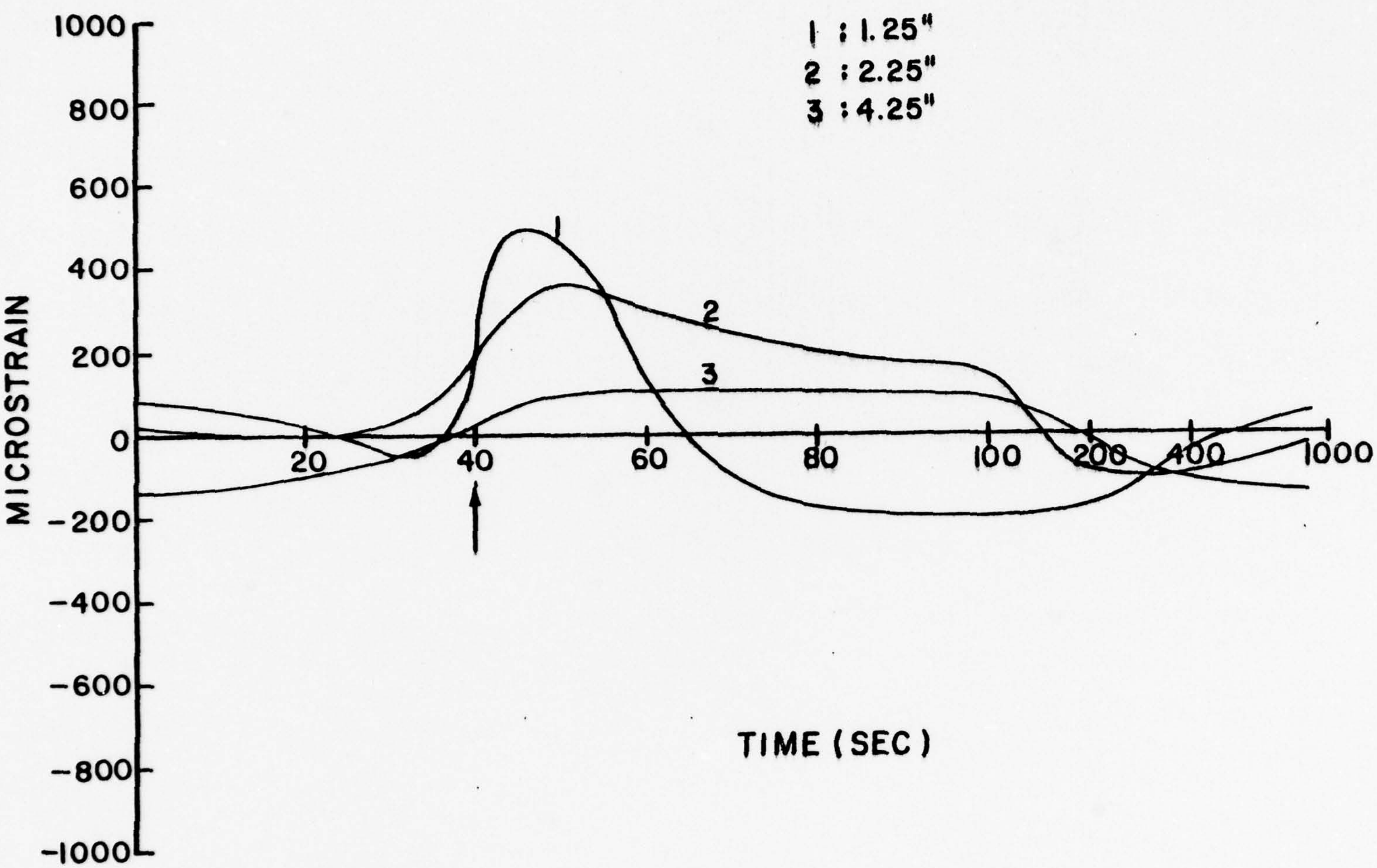


FIGURE 5 HY-130 Specimen I, Experimental Results, Pass 4

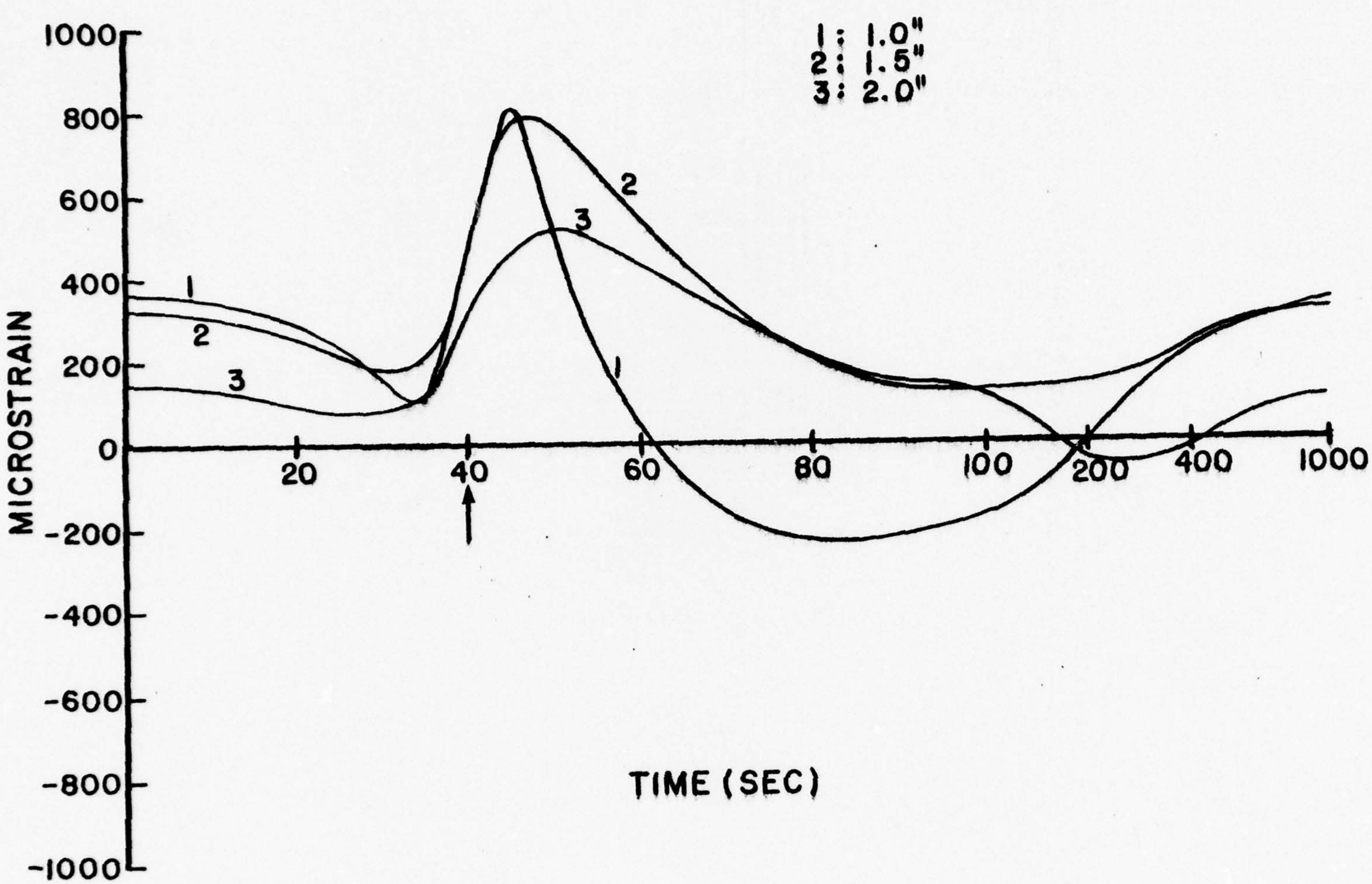


FIGURE 6 HY-130 Specimen II, Experimental Results, Pass 4

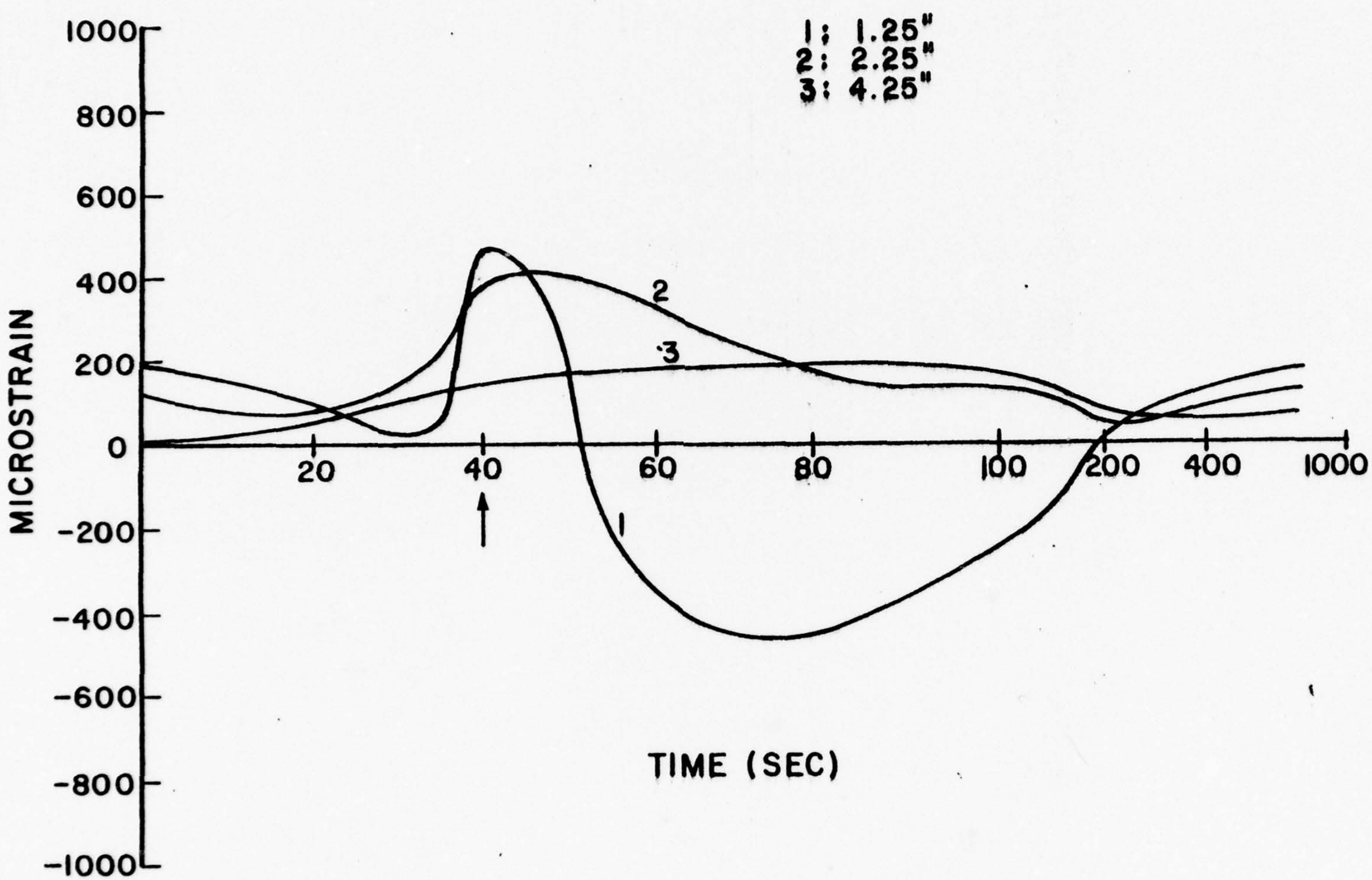


FIGURE 7 1020 Steel, Experimental Results, Pass 4

start from the origin, indicating that some strain has been already accumulated from the previous passes.

Figure 8 shows experimental results for the second HY-130 specimen as measured 0.6 inches from the weld line. This case is shown separately because of the interesting results recorded. The 0.6 in. location was the closest point of measurement and the first notable observation is that the strains which exist between passes reach very high levels in tension. These strain levels are approximately four times the interpass strain levels measured at 1.0" from the weld line. The second notable aspect of the curves is the rapidity in which the strain changes from a smoothly decreasing tensile strain to a high tensile peak and then returns to a smoothly decreasing tensile strain for passes 2, 3, and 4 (not shown). Following these strain movements, pass 5 shows no tensile peak at all but rather the strain starts at a high tensile strain level, reaches a minimum, and returns to a high tensile strain level.

This behavior resembles that reported by Klein in his study on 3/4" thick HY-130 plate. He reported two tensile peaks at points 1.0" or closer to the weld line. The differences between these results and those of Klein are most likely caused by the fact that his specimens were highly restrained whereas the specimens in this study were unrestrained. Klein attributed this behavior to the possibility that precipitates form in the fusion zone and weld metal upon solidification which will cause high tensile strains in the metal near the weld line. Stoop and Metzbower recently reported that the microstructure in the HAZ of GMA weldments of HY-130 consisted of coarse grained Bainite close to the fusion zone and autotempered Martensite plus Ferrite further away from the fusion zone. Outside the HAZ, the base metal remained tempered Mortensite.

At this point a metallurgical characterization study of the weldment must be undertaken to support the above conclusions.

2.3.2 EB Welding Tests

The electron-beam welding tests were carried out by Coneybear, using the facilities of the Applied Energy Company, since no such facilities were available at M.I.T. The welding was performed using a Hamilton Zeiss Model SW5 machine with vacuum tank diameter and length 54" and 96" respectively.

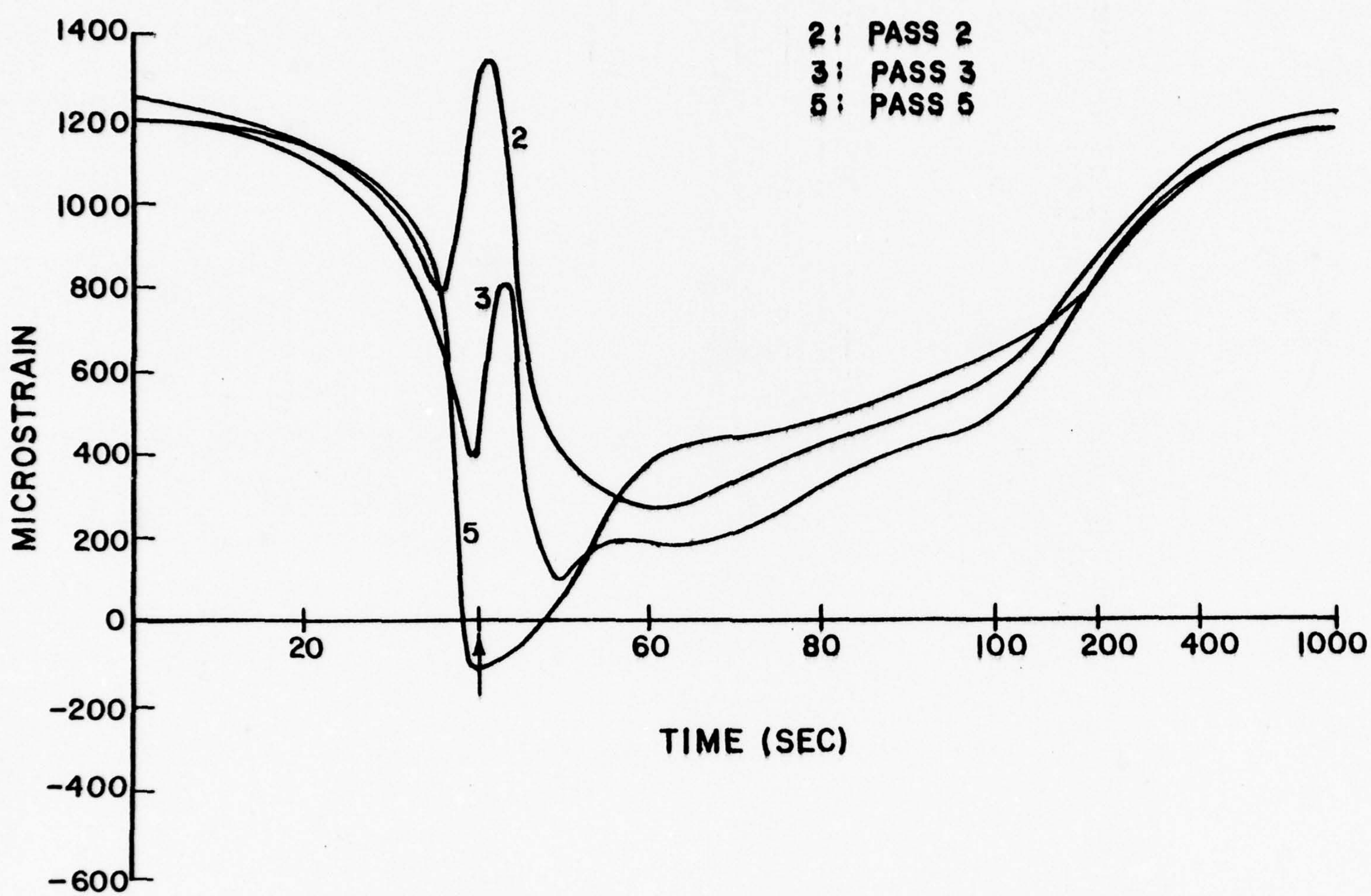


FIGURE 8 HY-130 Specimen II, Experimental Results at 0.6" from Weld Line

The maximum power available from this machine is 7.5 kW at 150 kV and 50 mA, while the vacuum obtained measures 2×10^{-4} torr.

A total of four experiments, two with 1020 and two with HY-130 steel plates, were performed during this investigation. Only two of these welds yielded experimental results, however. The first experiment, using 1020 steel plates, was conducted in order to determine the appropriate welding parameters. No measurements were taken during this test, except for the use of heat sensitive paint to get a rough estimate of the temperature distribution. After this test was performed, the following welding conditions for the remaining cases were decided upon:

Voltage = 150 kV

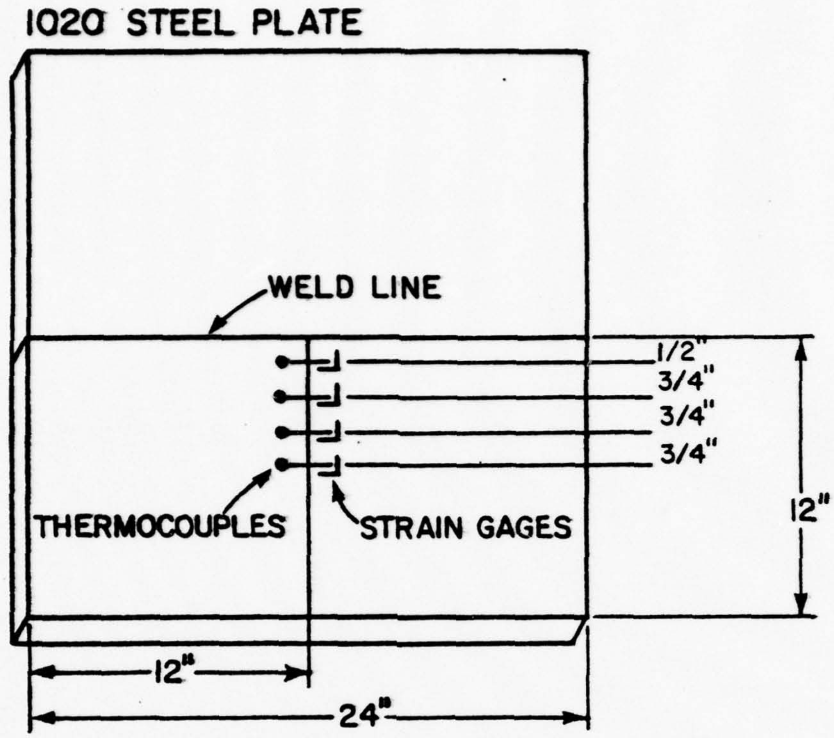
Amperage = 0.045 A

Travel speed = 0.25 in/sec (15 ipm)

The second experiment, using HY-130 plates, was intended to be used for recording temperatures and strains during welding. The test was unsuccessful however, because it was found that the beam deflected away from the joint. Although the operator can aim the beam to some extent by the use of a magnetic field, it was not possible to keep the beam directed at the joint. Upon investigation, it was found that the plates were magnetized. This incidence prompted the use of wire coils to demagnetize the plates prior to the last two tests.

The last two tests, one using 1020 plates and one using HY-130 plates, were successful. Transient thermal strains and temperature changes were measured during the welding and cooling periods much in the same way as with GMA welded specimens. Figure 9 shows the specimen configurations and the locations of the strain gages and thermocouples for both specimens. It should be repeated here that the joint configuration was that of a square butt and that the welding was performed in one pass only.

The experimental results obtained are reported in Coneybear's thesis. Some representative results are included here in Figures 10 through 20. These figures show measurements of temperature, longitudinal strain, and transverse strain as a function of time for the 1020 steel (at 0.5" and 2.75" from the weld line) and the HY-130 steel (at 0.67" and 1.31" from the weld line) specimens. Shown on the same figures are results obtained using the M.I.T. one-dimensional computer program. Comparisons between the two



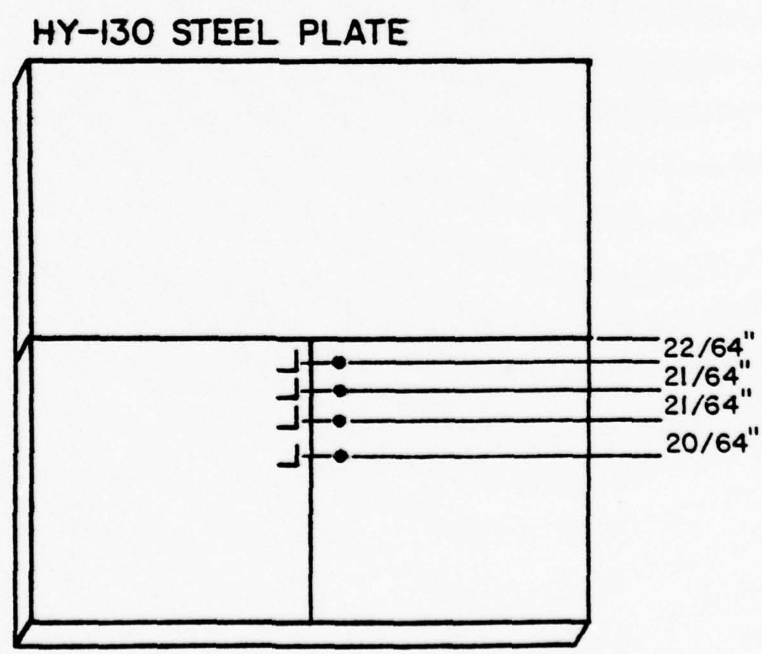


FIGURE 9 Thermocouple and Strain Gage Locations on EB Welded Specimens

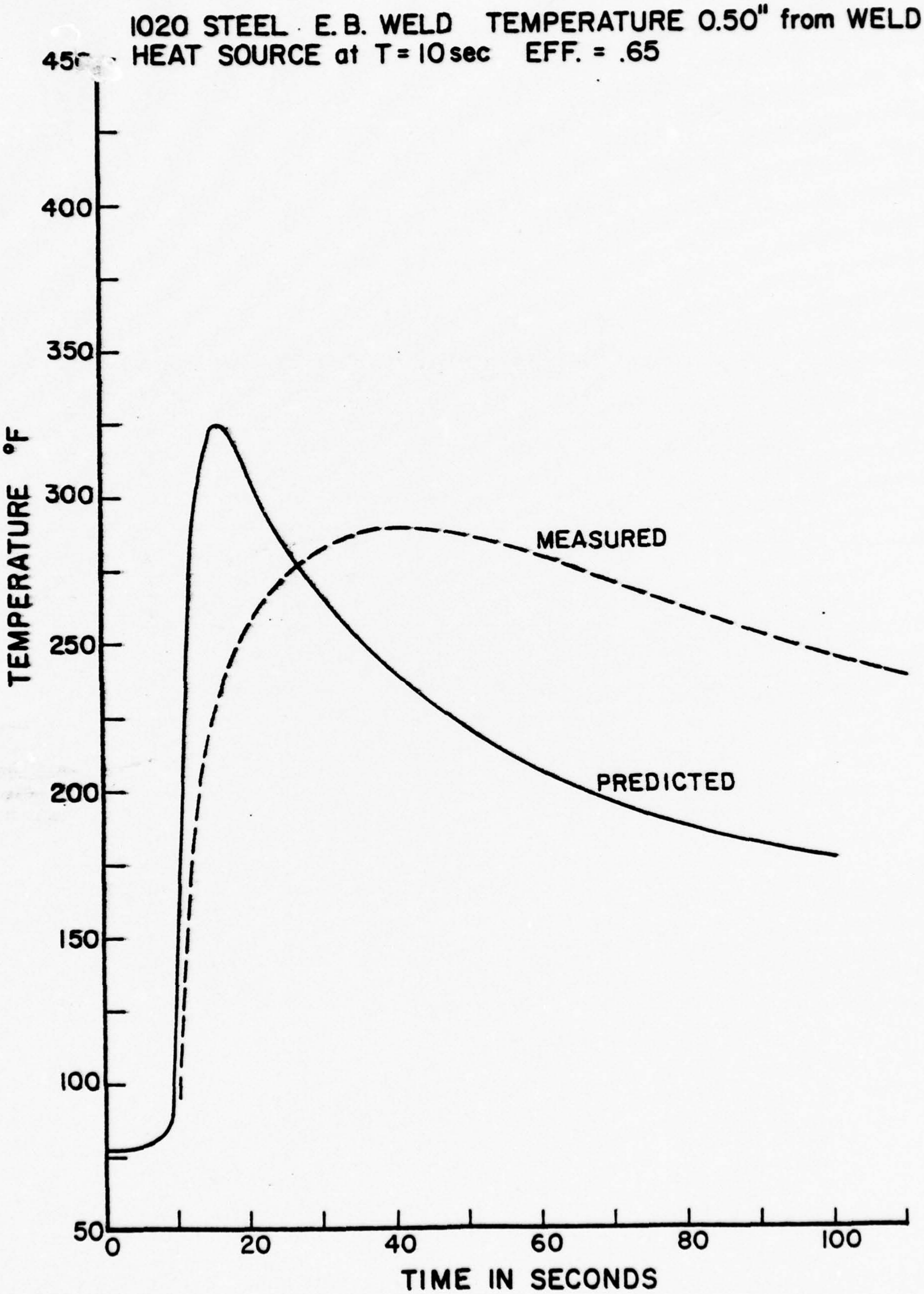


FIGURE 10 Temperature vs. Time - 1020 Specimen (EB)
0.5" From Weld Line

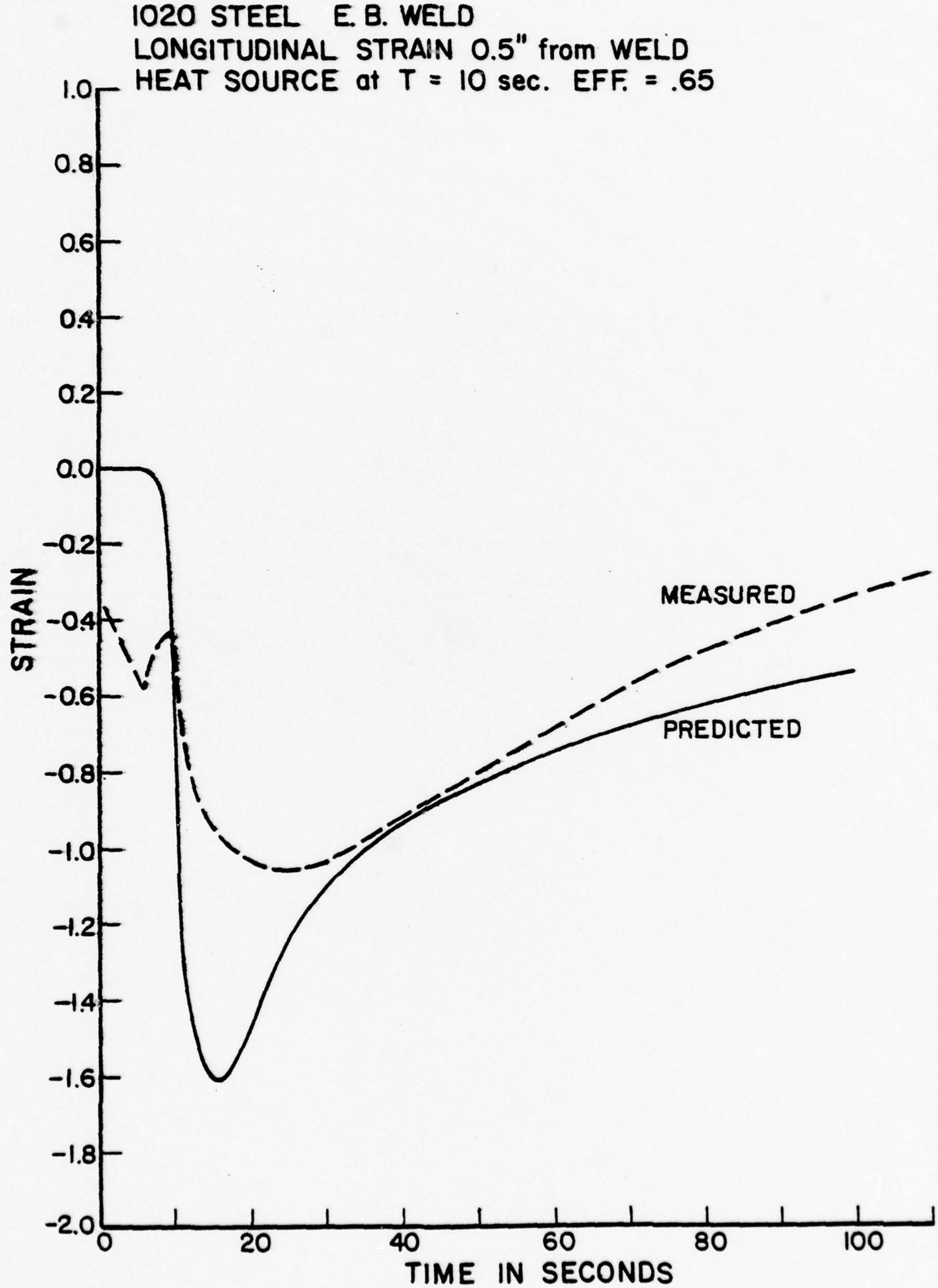


FIGURE 11 Longitudinal Strain vs. Time - 1020 Specimen (EB) 0.5" From Weld Line

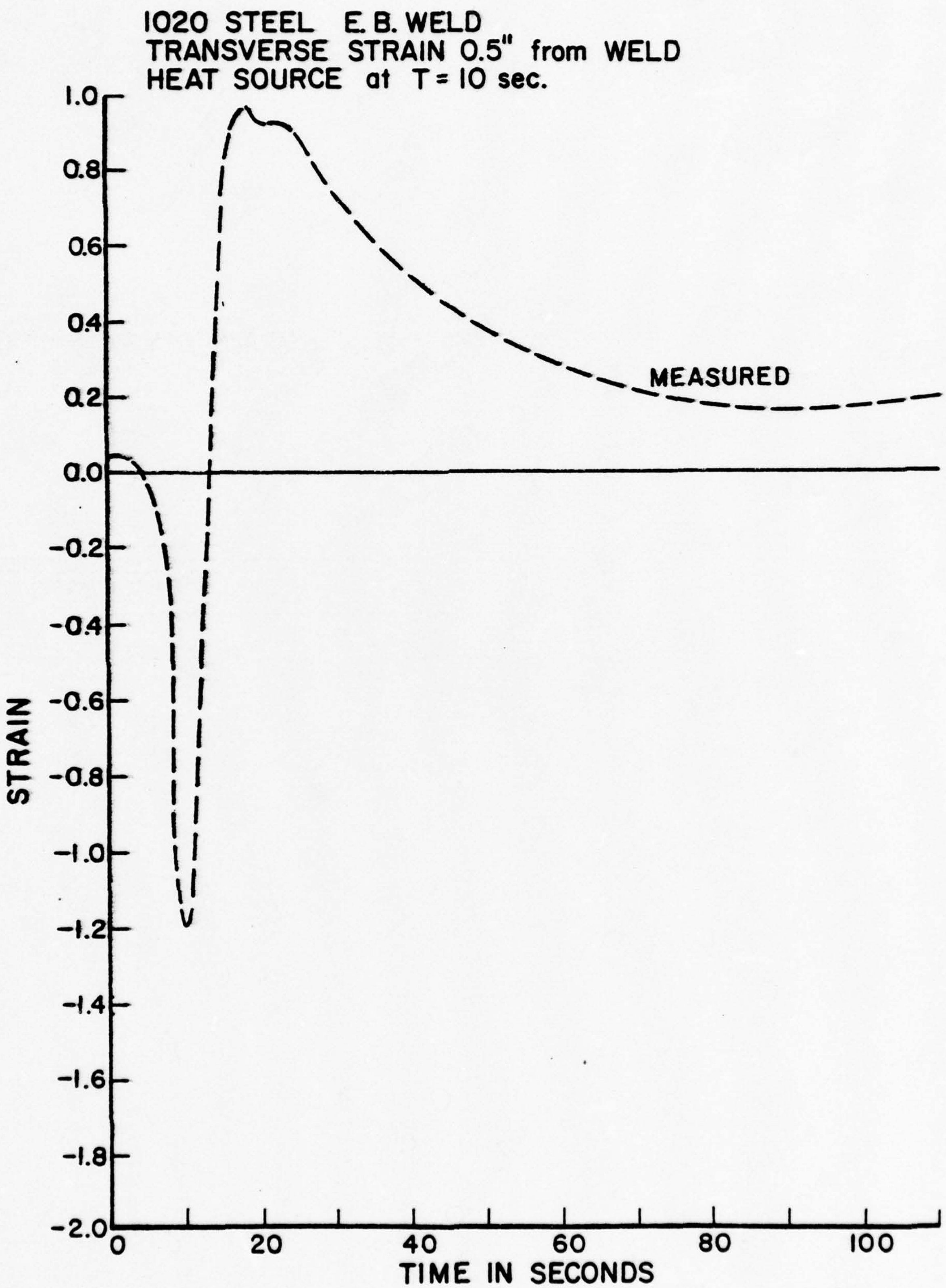


FIGURE 12 Transverse Strain vs. Time - 1020 Specimen (EB) 0.5" From Weld Line

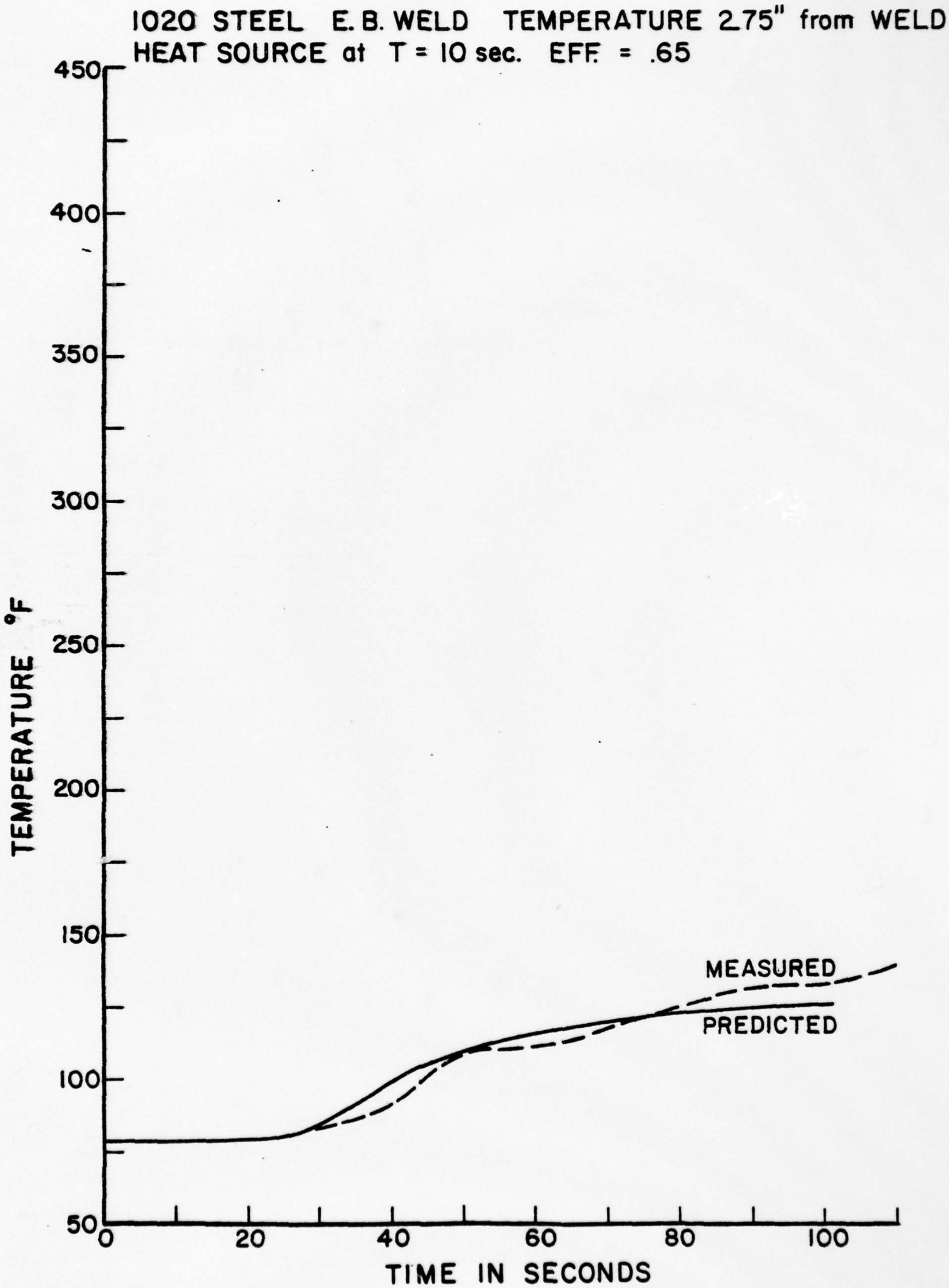


FIGURE 13 Temperature vs. Time - 1020 Specimen (EB)
2.75" From Weld Line

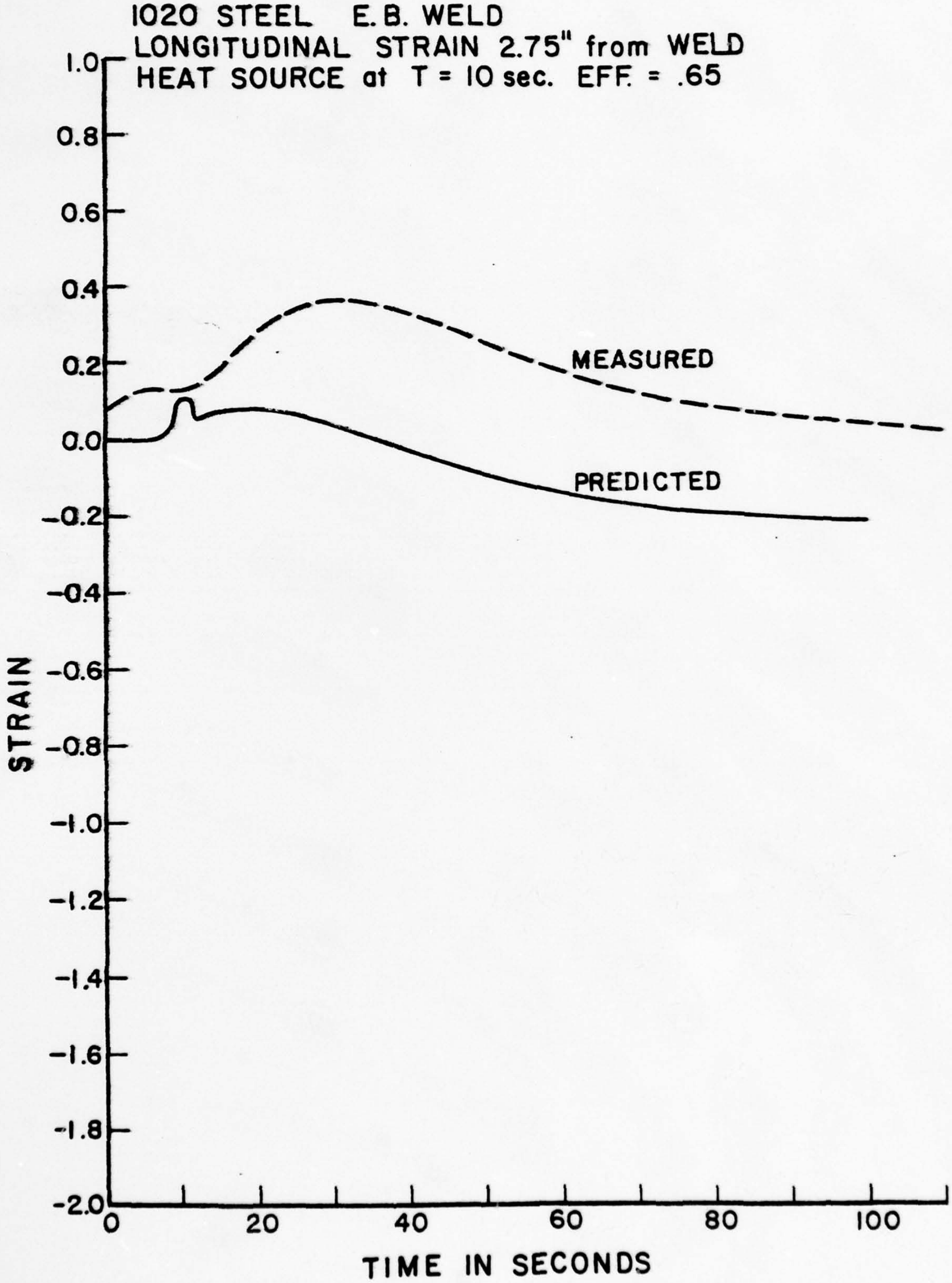


FIGURE 14 Longitudinal Strain vs. Time-1020 Specimen (EB) 2.75" From Weld Line

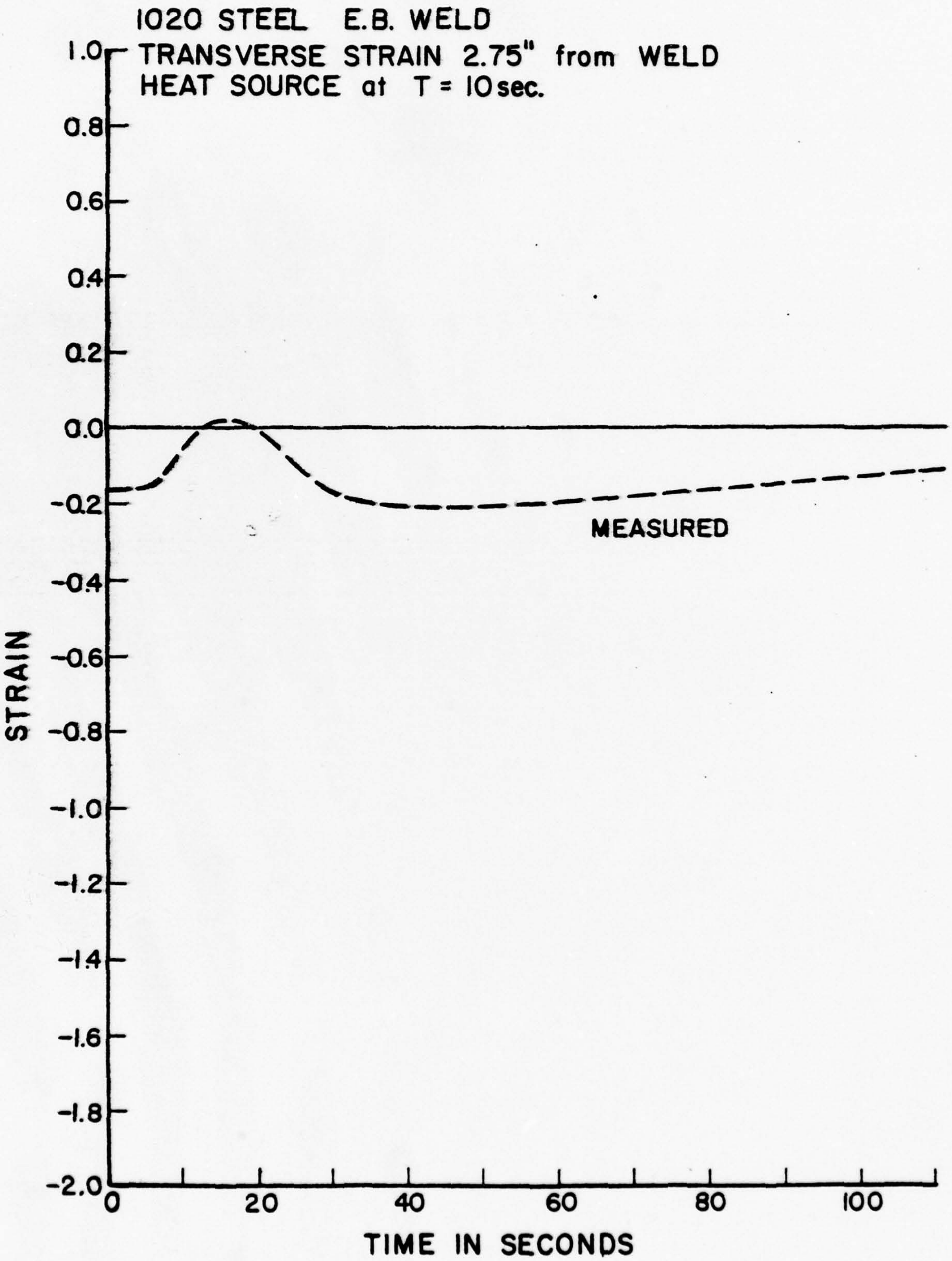


FIGURE 15 Transverse Strain vs. Time-1020 Specimen (EB)
2.75" From Weld Line

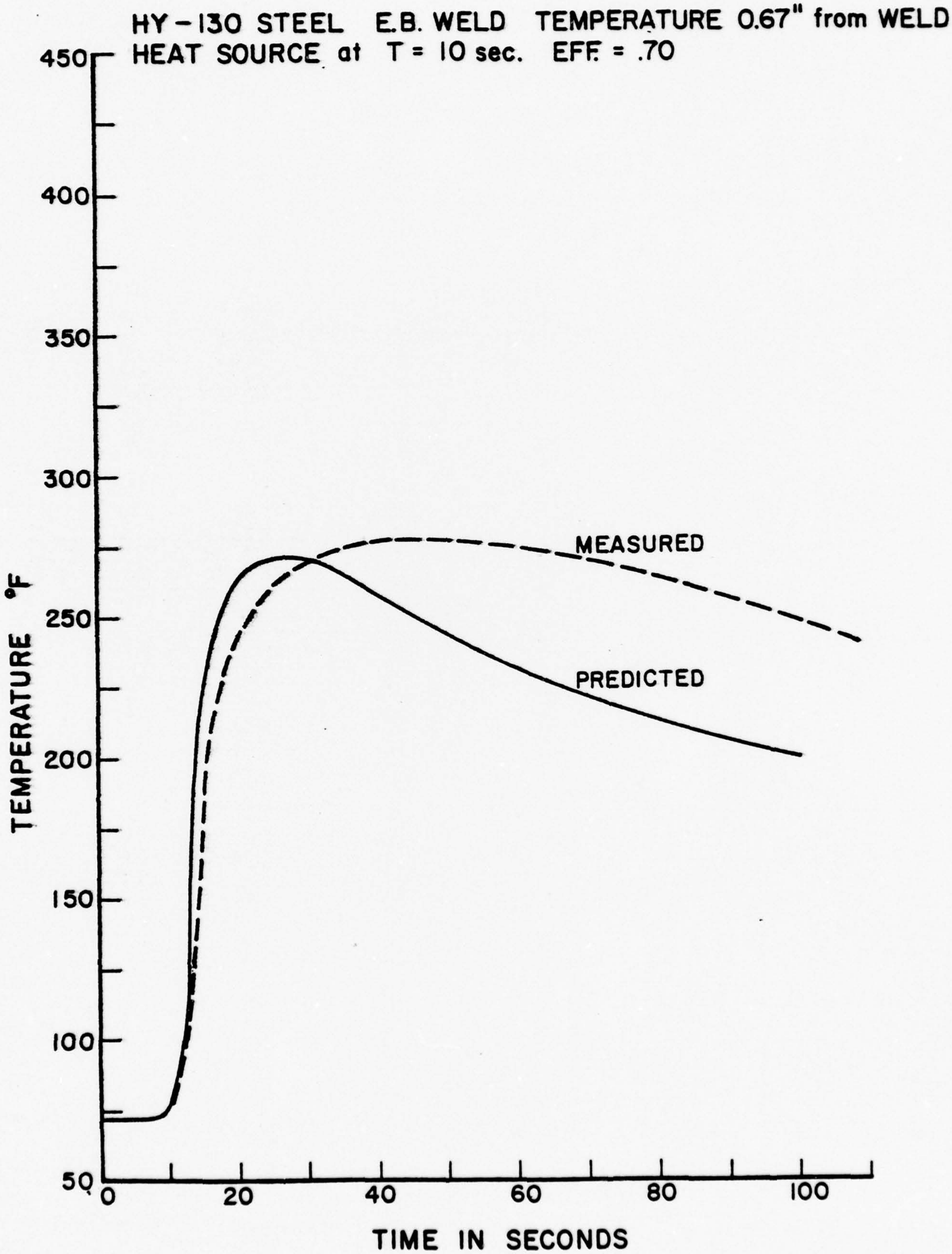


FIGURE 16 Temperature vs. Time - HY-130 Specimen (EB) 0.67" From Weld Line

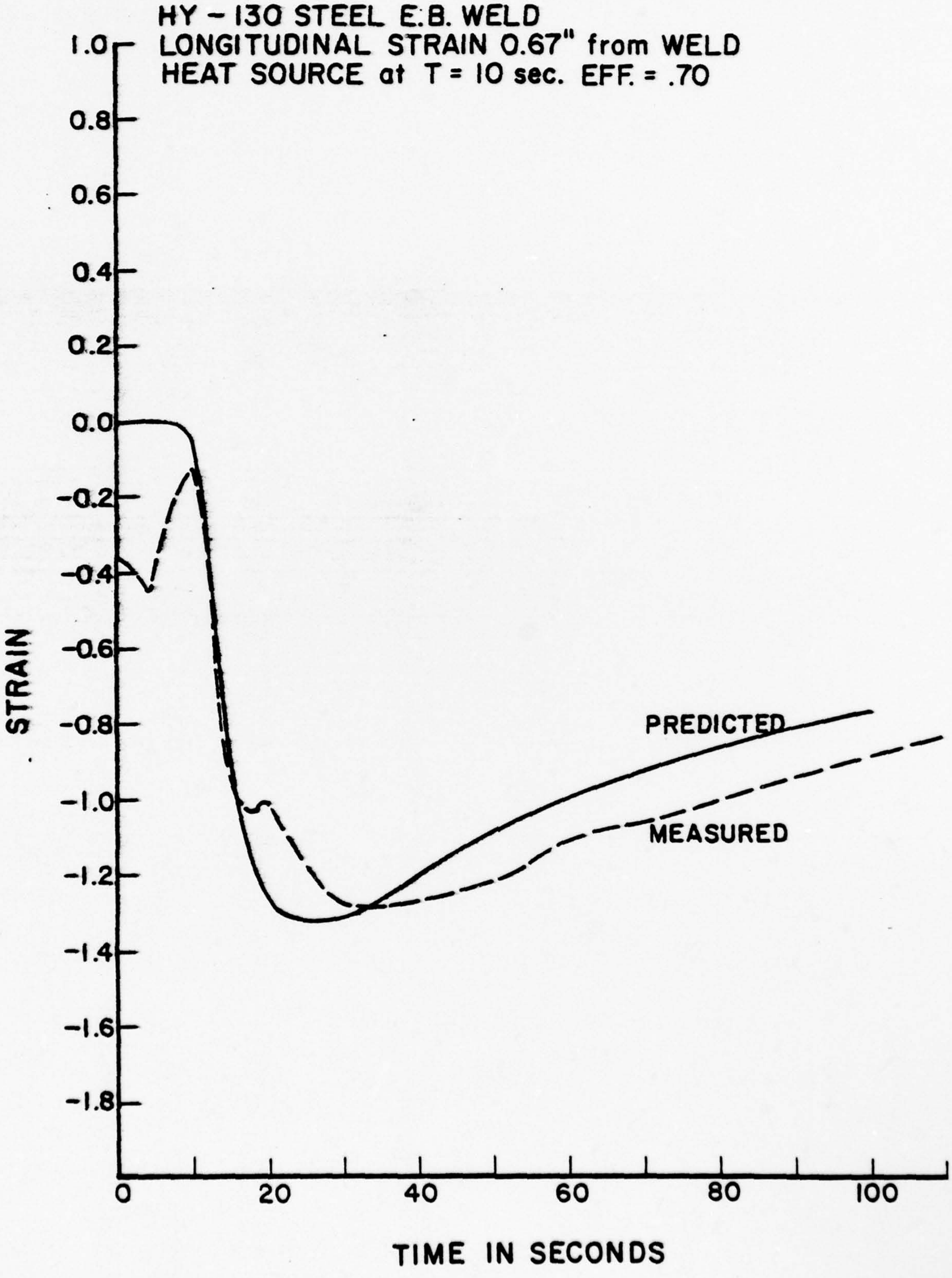


FIGURE 17 Longitudinal Strain vs. Time — HY-130 Specimen (EB) 0.67" From Weld Line

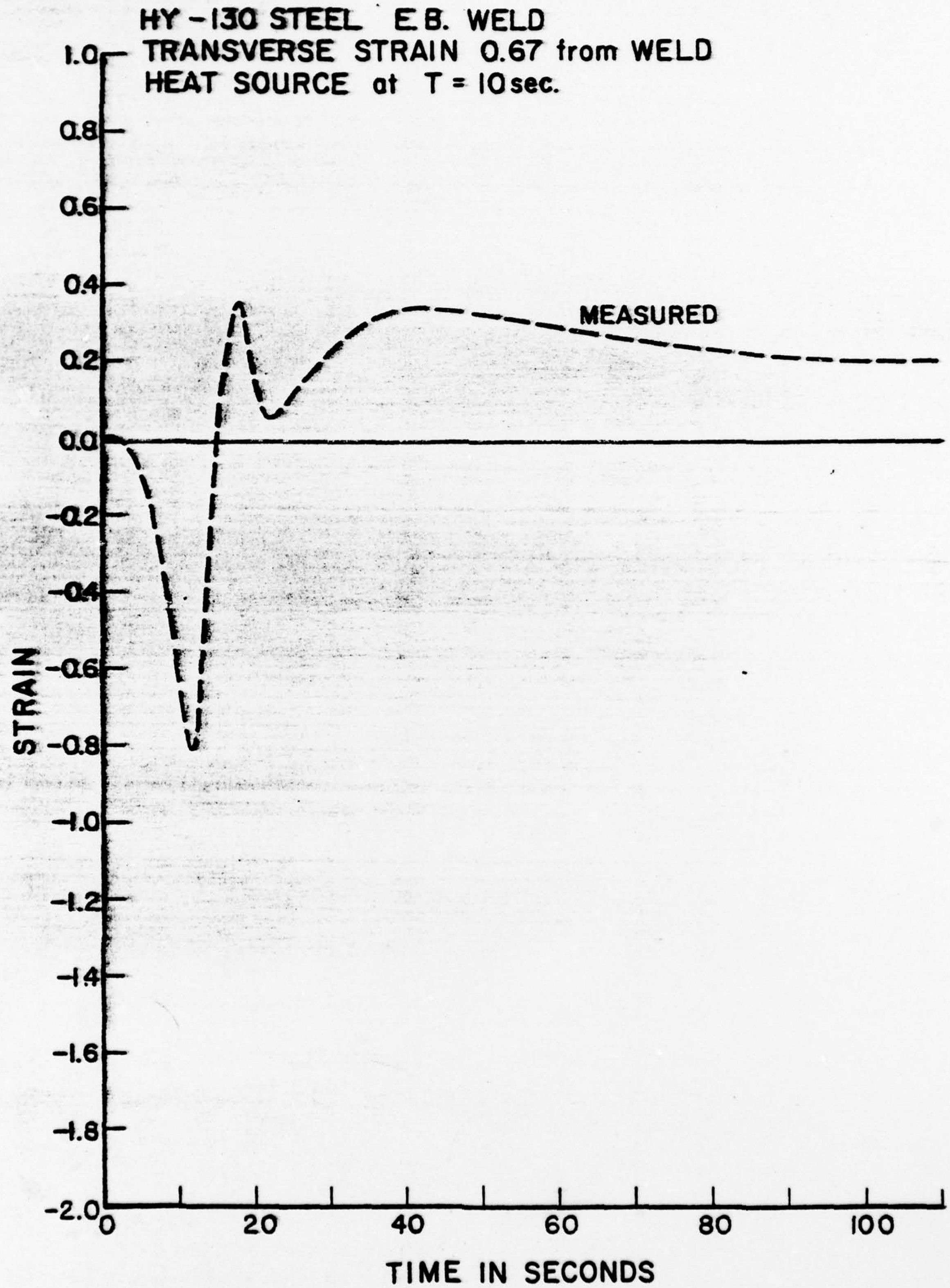


FIGURE 18 Transverse Strain vs. Time - HY-130 Specimen (EB) 0.67" From Weld Line

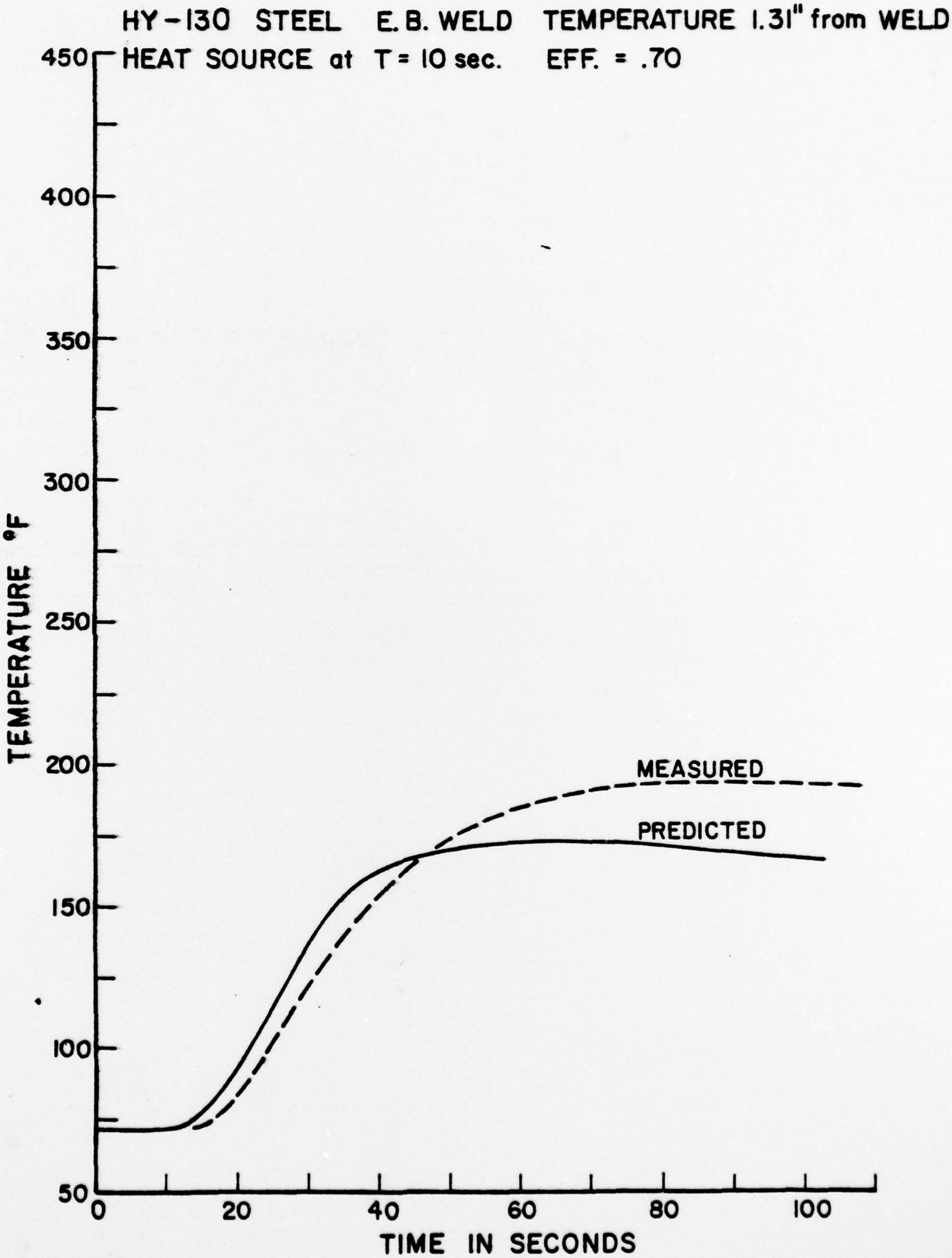


FIGURE 19 Temperature vs. Time - HY-130 Specimen
1.31" From Weld Line

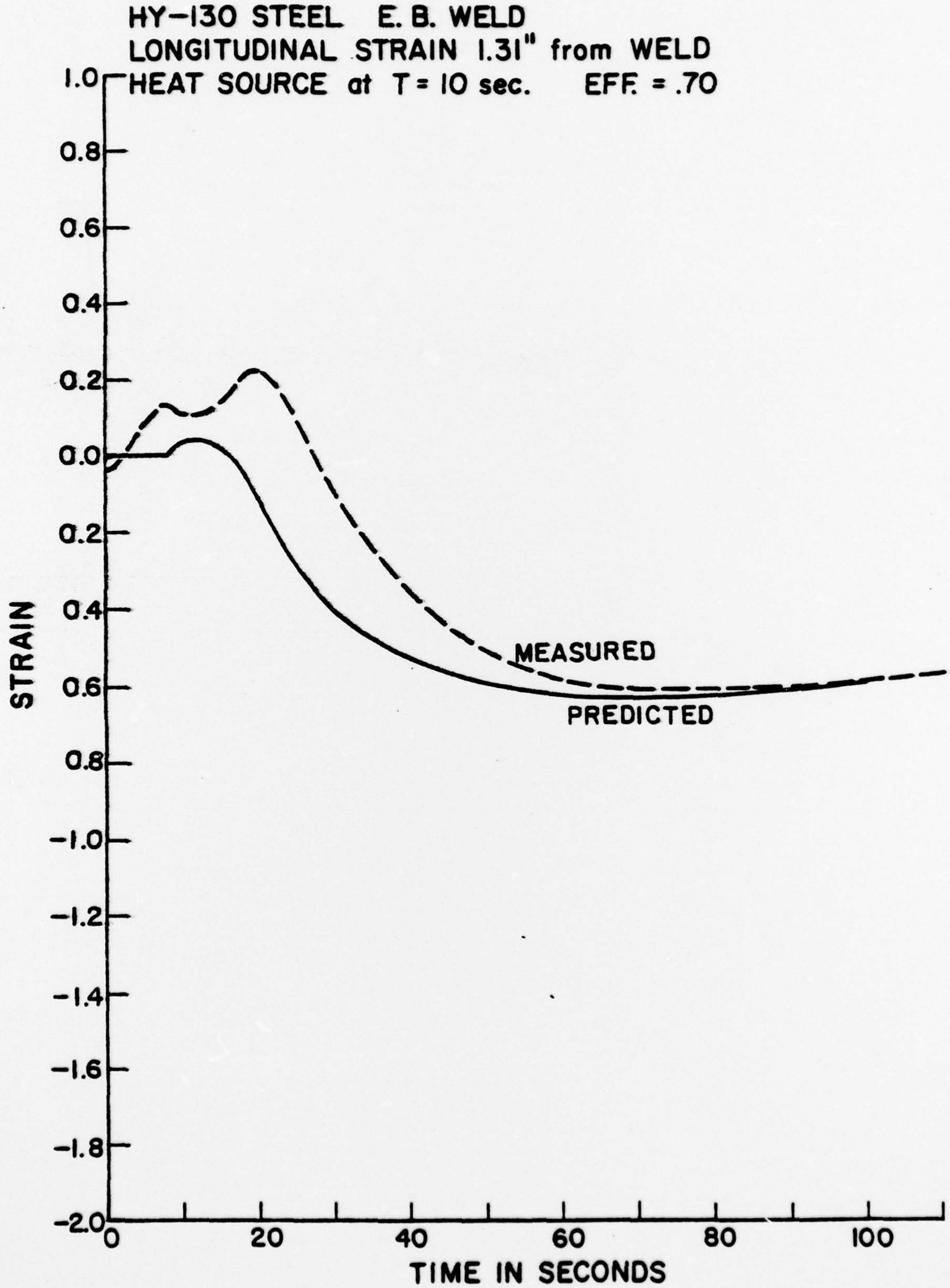


FIGURE 20 Longitudinal Strain vs. Time — HY-130 Specimen 1.31" From Weld Line

will, however, be discussed in the next Section.

The following observations can be made. First of all the results for both tests are qualitatively the same, something which was expected. Second, in some cases, especially close to the weld, the transverse strain can be as high as the longitudinal strains. Finally, the peculiar results found in the longitudinal strain history of the GMA welded HY-130 specimens (see Figure 8) were not repeated here (see, for example, Figure 17). This last observation has not been explained yet and it is expected that a deeper investigation will be undertaken.

2.4 Analysis of Data Obtained in Step 1.2 (Step 1.3)

2.4.1 One-dimensional Computer Program

Both Lipsey and Coneybear compared the experimental results with predictions made using the M.I.T. one-dimensional computer program for the analysis of thermal strains and metal movement during welding. The program had, though, to be modified by Papazoglou to account for some numerical instabilities which occurred during the first trial runs.

Figures 10 through 20 show how the results obtained by the computer compare with the experimental ones for the case of the electron-beam welding. Figures 21-24 show typical results for the case of the multipass gas metal arc welding. The results for pass 3 were arbitrarily chosen as they are entirely typical of the comparisons for all passes.

Immediately apparent upon looking at the figures is the fact that the temperature comparisons are very good, whereas the strain comparisons are not very good in most cases. In calculating the temperature, the computer program treats the temperature distribution around the moving arc as a two-dimensional heat-conduction problem. It appears that this approach is adequate to describe the temperature distribution in the plates. Of interest is the fact that the arc efficiency used for calculating the temperature distribution was the same for both HY-130 and 1020 steel for the GMA process and almost the same for the EB process. This supports the contention that arc efficiency is only a function of the welding equipment used and not a function of the material being welded.

A point should be made here regarding the arc efficiency of the electron-beam welding process. In conventional arc welding processes, the arc efficiency

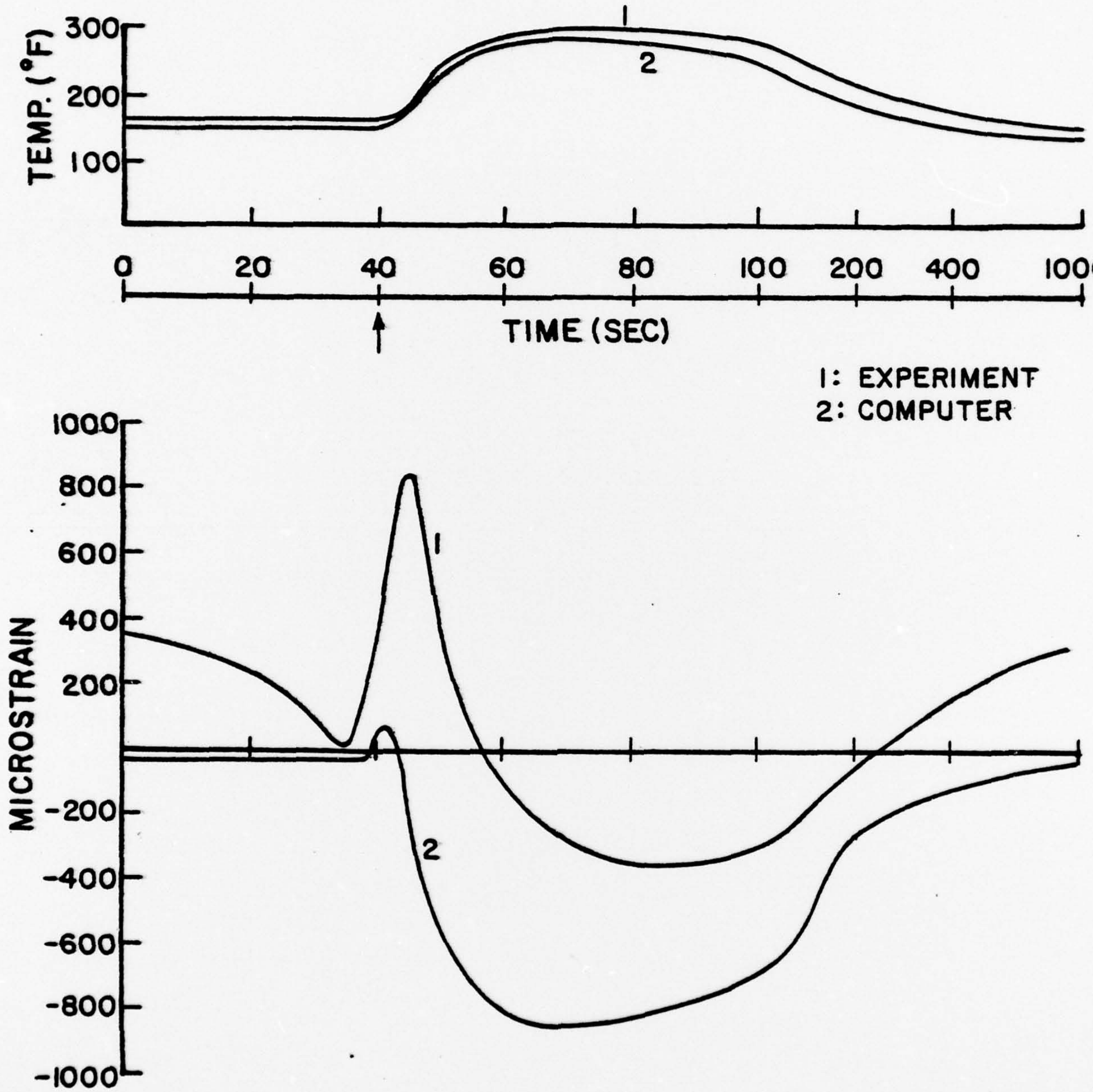


FIGURE 21 HY-130 Specimen II, 1.0", Temperature And Strain Analytical Comparison, Pass 3

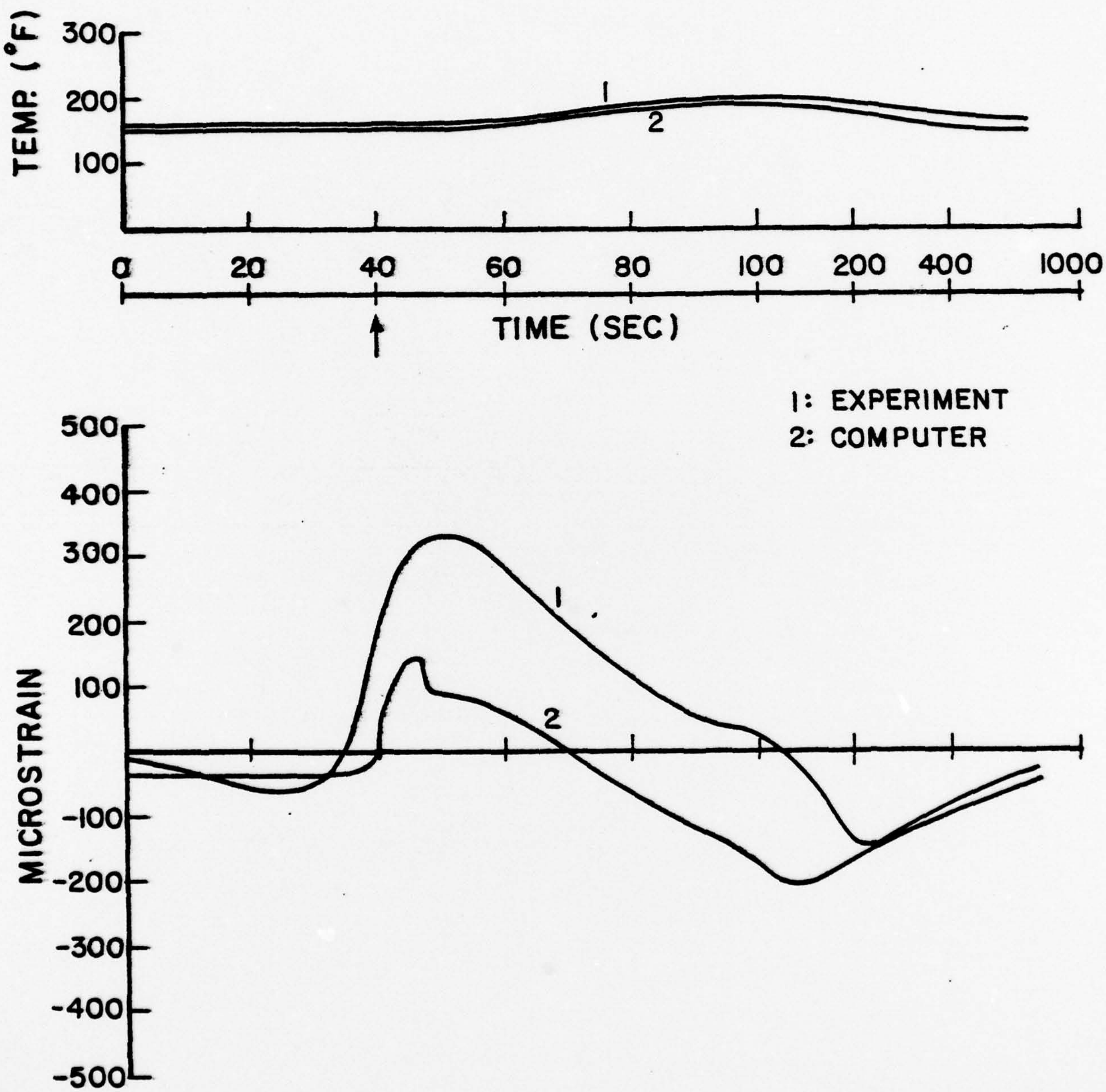


FIGURE 22 HY-130 Specimen I, 2.25", Temperature And Strain Analytical Comparison, Pass 3

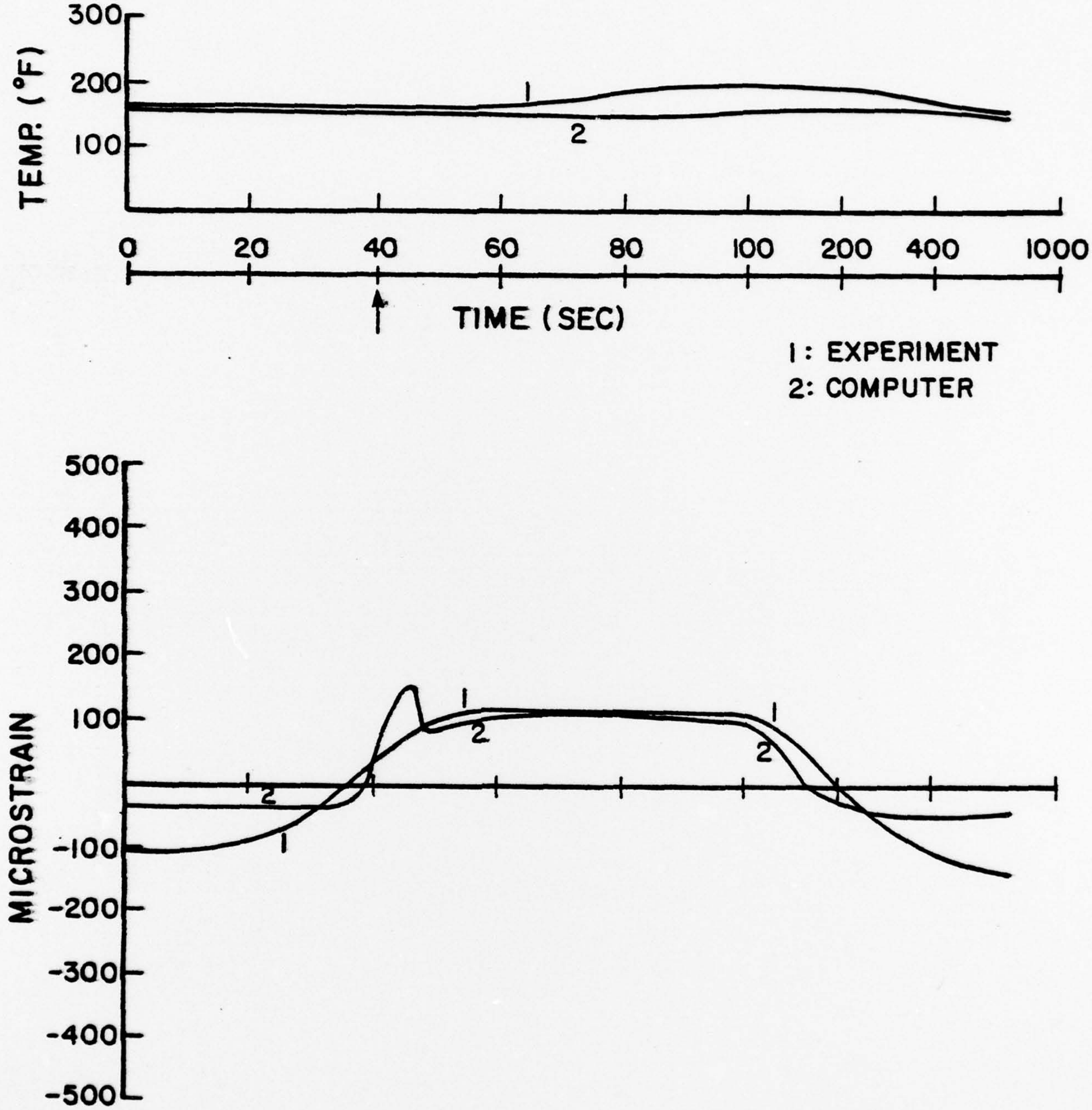


FIGURE 23 HY-130 Specimen I, 4.25", Temperature And Strain Analytical Comparison, Pass 3

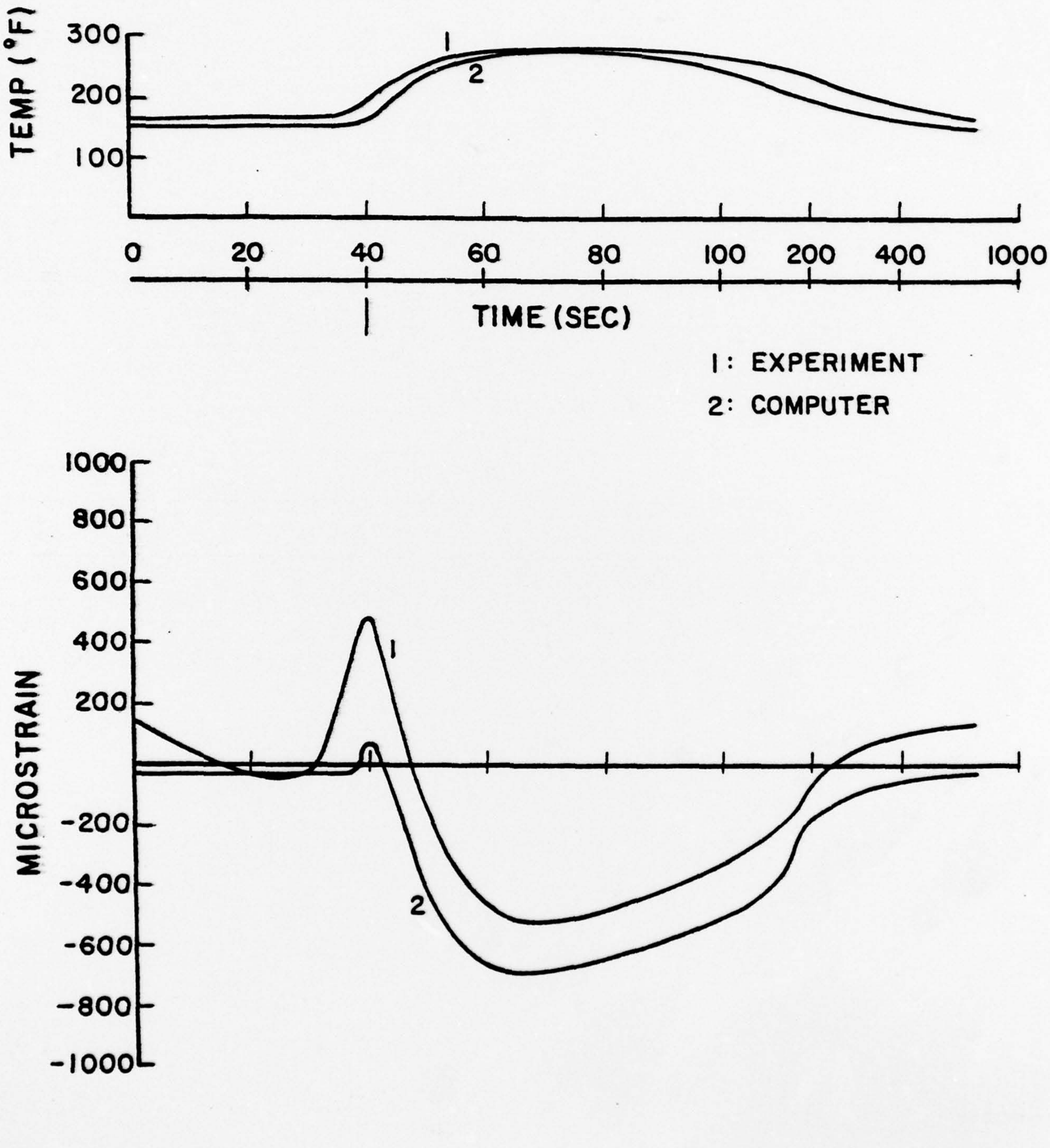


FIGURE 24 1020 Steel, 1.25", Temperature And Strain Analytical Comparison, Pass 3

is used as an approximation of the various energy losses that occur between the welding arc and the workpiece; so, the final heat input is given as the product of the arc efficiency, the arc voltage, and the arc current. In the EB process, however, there is no such thing as an arc and the voltage and current measured are the ones that are input to the machine itself. Consequently, the definition of the arc efficiency has to be modified in the case of the EB process to include the energy losses inside the machine. Having clarified this, however, one is astonished to discover that arc efficiencies in the vicinity of 0.70 are necessary, if one wants to match analytical with experimental results. Such low arc efficiencies, though, cannot be explained easily, especially if one bears in mind the facts that the process takes place in a vacuum and that electric machines have usually very high efficiencies. It is thus concluded that more investigation is needed on the subject.

In analyzing strains, the one-dimensional program assumes that the longitudinal strain is only a function of the transverse distance from the weld and the transverse strain as well as the shear strain are assumed to be zero. In fact, the transverse strains measured were not zero and for distances from the weld line of up to approximately one inch, the transverse strains were of the same order of magnitude as the longitudinal strains. At transverse distances of approximately two inches, transverse strains are greatly reduced, but still significant. Only at greater transverse distances do they become relatively insignificant. It is thought that the presence of these transverse strains accounts for the poor comparisons between the experimental results and the one-dimensional program predictions because the assumptions used in calculating the longitudinal strains are not valid in these one inch thick plates. However, it can be seen that the results for the point 4.25" away from the weld line (Fig. 23) agree more closely than for points closer to the weld line. This appears to be due to the absence of any significant transverse strains this far from the weld line.

Another cause of the poor agreement between experimental and analytical results at points near the weld line is the finite size of the gages used. The strain gages measure about .3" across. When a high strain gradient exists, the side of the gage closest to the weld may be subject to a strain quite different than that seen by the side .3" away, resulting in experimental errors.

The above discussion leads to the conclusion that a two-dimensional program should be used for predicting thermal strains during welding.

2.4.2 Two-dimensional Computer Program

No effort has been made yet to use the existing M.I.T. two-dimensional plane strain finite element computer program to analyze thermal strains during welding (this program is described in Section IV, Manual #3 of the monograph "Analysis of Welded Structures: Design and Fabrication Considerations".) The decision for not using it has been discussed with representatives of the Office of Naval Research and the Electric Boat Division of General Dynamic Corporation during a meeting held at M.I.T. on July, 1978. All parts agreed that such a step was justifiable on the grounds of previous experience with the program and its high running cost.

It was instead proposed that an effort should be undertaken to include capabilities for handling welding problems in the existing multi-purpose finite element programs ADINA and ADINAT developed by Prof. K. J. Bathe, Department of Mechanical Engineering, M.I.T. The first of these programs deals with stress analysis and the second with temperature analysis. The decision to use these two programs was based on a number of factors. First, these programs have been extensively tested in the past and were found to be both accurate and efficient. Second, the welding problem is an integral part of the more general structural analysis problem, so that compatibility between programs dealing with these problems is considered essential. For this reason a general purpose finite element program had to be selected and ADINA seemed to be the most appropriate since it was developed at M.I.T. Third, Papazoglou, who will be the one principally involved in the analytical part of this contract, has past experience in using both ADINA and ADINAT.

Inital contacts have already been made with Prof. Bathe, and he is willing to supply us the appropriate parts of both programs free.
Based on these parts, new subroutines will be written implementing the welding model developed. It should be understood, however, that only these subroutines will be supplied to the Office of Naval Research at the end of the 3-year contract. We will not be able to supply ONR with the parts of the ADINA and ADINAT given to us by Prof. Bathe, since that was part of the agreement with Prof. Bathe. It should also be understood that Prof. Bathe will have access

to the subroutines developed during the 3-year period.

Regarding the welding model which includes effects of metallurgical transformation and multipass welding, it is reported that initial mathematical formulations have been done by Papazoglou as part of his doctoral thesis. It is believed that within the next few months the final model will have been developed, so that the computer implementation can start. More details on this subject will be included in the proposal for the work to be conducted during the second year of this project.

3. PROGRESS OF TASK 2 - CYLINDRICAL SHELL

December 1, 1977 to August 31, 1978

3.1 General Status

According to the original proposal dated July, 1977, the research during the first year would include the following, under Task 2:

2.1 Development of details of research plan during the first year.

2.2 Experiment of girth welding along a groove of a cylindrical shell.

2.3 Analysis of data obtained in 2.2

This research program has been modified as explained in the next paragraph.

3.2 Development of Details of the Research Plan During the First Year (Step 2.1)

It was originally proposed that an experiment would be made during the first year on temperature and strain changes during girth welding along a groove of a cylindrical shell. During discussions, however, among the M.I.T. investigators involved in this research project it was decided to skip this test and proceed to Step 2.6 of the original proposal (see Table 1), namely to that of welding two unstiffened cylindrical shells. The reason behind this decision was that it was felt that this second test represented a more realistic simulation of practical applications. These facts were communicated to representatives of the Office of Naval Research and received a positive response. The decision was thus finalized. It was furthermore decided to perform the experiment using low-carbon steel cylinders, since HY-130 specimens could not be found at that time.

Regarding the analysis of data obtained in the experiment, it was felt that a delay would be appropriate for the same reasons as the ones discussed for the case of thick plates in Section 2.4.2. Note that in the case of welding cylindrical shells one-dimensional analysis is not possible.

3.3 Experiment on Butt Welds Between Unstiffened Cylindrical Shells (Step 2.6)

The experiment consisted of butt welding two unstiffened cylindrical shells 18 inches in diameter (OD), 1/2 inches thick and each being 30 inches long. The material used was mild steel. It is once more emphasized here that one of the major reasons for conducting such an experiment was to obtain some experience with the experimental procedure. This experience will be very helpful in dealing with the HY-130 cylindrical shells.

Figure 25 shows the weld joint configuration of the specimen. The welding was performed using the GMA welding process with 0.045 in. diameter Linde 65 type filler wire. Four passes were necessary to conduct the welding. The preheating and interpass temperature was 150°F.

Three kinds of measurements were taken during the welding and cooling stages of the experiment.

(1) Transient thermal strains were measured using adhesive bonded, electric resistance strain gages.

(2) Temperature changes were measured on the surface on the specimen using adhesive bonded, Chromel/Alumel thermocouples.

(3) Radial distortion was measured using two dial gages.

The results of the experiment are currently being appraised and analyzed. Although they are not essential for this contract, it is likely that they will be reported in the second annual progress report next year.

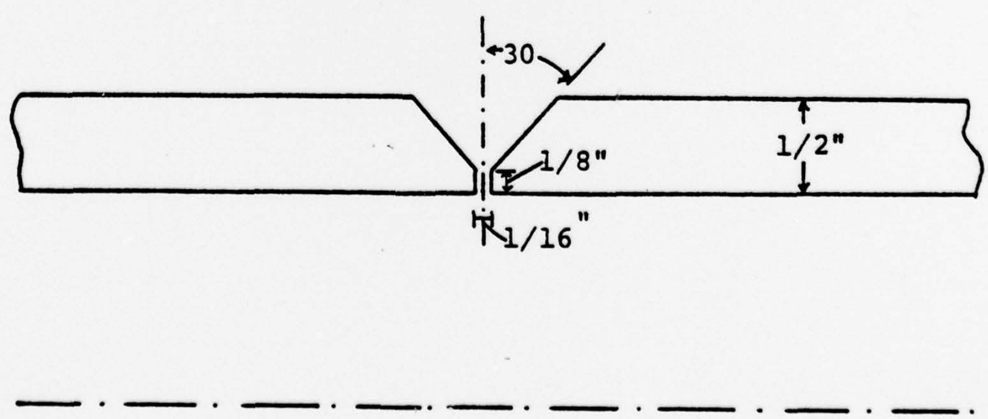


FIGURE 25

4. PLAN FOR THE SECOND YEAR

4.1 Task 1 - Thick Plate

It is expected that the work to be done in the second year of this research contract on Task 1 will be carried-out as originally proposed (see Table 1). Experiments will be carried out to measure the residual stresses (Step 1.5) of the specimens already welded in Step 1.2. Although details of the measurements have not been developed yet (for example technique to be used), it is expected that they will be performed some time in the spring of 1979. The same is true for the experiments on the simple restrained butt welds.

Regarding the analytical part of Task 1, Papazoglou hopes to have developed an initial version of the computer program early in the spring of 1979. This program will be capable of predicting temperature distributions, transient strains and residual stresses during the welding of thick plates. The plane-strain assumption will be used.

After the development of the program, a comparison will be made between the predicted results and the experimental results obtained in Steps 1.2 and 1.5.

4.2 Task 2 - Cylindrical Shell

Experiments will be performed on butt-welding two unstiffened cylindrical shells made of HY-130 steel. The experiment done with the mild steel shells during the summer of 1978 is hoped to guide us towards conducting this one. We plan to conduct the experiment during the early part of 1979, but this date depends very much on the date the specimens will be received, as promised, from the U.S. Navy.

An analytical evaluation of the obtained results will also be made using a modified version of the computer probram developed under Task 1. If such a modification is not possible at the time, a more simplified program, already developed by Muraki, will be used.